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(54) Secondary emission coating for photomultiplier tubes

(57) A p-doped diamond film deposited upon a substrate is used to make exceptionally stable high current secondary electron emitters for photomultiplier tube dynodes.

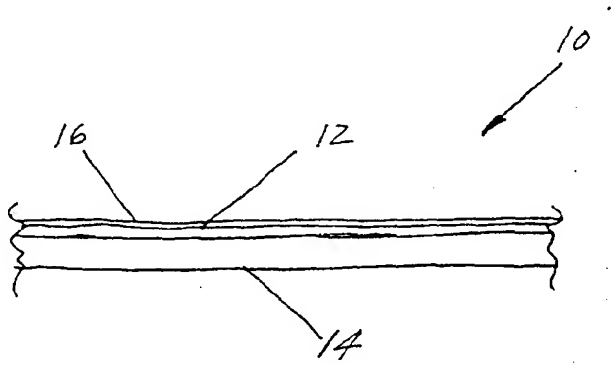

FIG 1

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Description

[0001] This invention deals generally with electron discharge devices, and more specifically with a secondary electron emitting surface constructed with diamond film and used in photomultiplier tubes.

[0002] Photomultiplier tubes have become commonly used for detecting low radiation levels. Typically such tubes consist of a glass envelope with an electron emitting photocathode located on the inside surface of a faceplate on the envelope. When radiation strikes the photocathode, electrons emitted from it are directed toward and collected by an electron multiplier.

[0003] The electron multiplier consists of several dynodes with secondary electron emitting surfaces, with the first dynode receiving the electrons from the photocathode. The electron multiplier has an electrical output which is directly related to the quantity of electrons collected by the first dynode, and increasing the ratio of the quantity of electrons at the output of the electron multiplier to the quantity of the electrons received by the first dynode is a continuing design goal. This ratio is largely determined by the gain of the individual dynodes, expressed in a simple number ratio, which indicates the number of secondary electrons emitted for every electron striking the dynode secondary emitter surfaces.

[0004] However, other criteria are also involved in providing a good secondary emitter. Two of these are hysteresis, a measure of variation in gain as a secondary emitter is first subjected to primary electrons, and count rate stability, a measure of the variation in pulse amplitude due to increasing pulse rate.

[0005] Existing secondary emitter materials including the most common, gallium phosphide, demonstrate low measures of such properties, but have other difficulties. For example, gallium phosphide requires special thermal activation in a vacuum during tube processing and it also requires the use of hazardous gases during its processing.

[0006] Secondary emitters with unmodified diamond films on substrates and alkali halide films on the diamond layer have also been disclosed in U.S. Patent 5,619,091 by Anderson et al. However, the high current densities required in later stage dynodes can cause electron deficient regions in such a pure diamond layer. This leads to the accumulation of electrical charge on the substrate and results in poor count rate stability.

[0007] It would be very beneficial to have a secondary emitter with gain and stability at least equivalent to those presently available, but without the difficulties and hazards of the current processing.

SUMMARY OF THE INVENTION

[0008] The present invention furnishes a modified diamond layer, a diamond layer with p-doping, applied to a standard substrate, preferably of molybdenum, for use as a secondary emitter in photomultiplier tube dynodes. In the preferred embodiment for a photomultiplier tube, the diamond layer is p-doped with boron.

[0009] Not only can the p-doped diamond layer provide higher gain, but a substantial additional advantage of such a p-doped diamond secondary emitter layer is that it has lower hysteresis and greater pulse rate stability than prior art secondary emitters, even the undoped diamond emitters.

[0010] The p-doped diamond film of the invention can also be placed on the substrate before being put into the tube. For prior art tubes it is common practice to evaporate antimony in-situ. Such antimony coating are applied from special sources installed in the tube which are activated while the tubes are being processed on the exhaust system. This method results in high secondary emission in the first dynode position, but since the antimony is evaporated in-situ, it is not uniform and hence can have a negative effect on pulse height resolution and sensitivity to external magnetic fields.

[0011] Gallium phosphide dynodes, which also provide exceptionally high secondary emission, require a hazardous fabrication process and require thermal activation during the exhaust process. Diamond deposition is not a hazardous process, and the dynodes do not require any special activation process.

[0012] However, it should be appreciated that during the exhaust processing of all photomultiplier tubes, it is typical to dose the tube with alkali metal vapor to generate the photocathode, and therefore some alkali metal coats the secondary emitter surfaces of the dynodes even when such surfaces are diamond films. However, such alkali metal coatings are beneficial to the operation of diamond secondary emitters.

[0013] From an operational standpoint the complete application and processing of the p-doped diamond layer outside the tube assures a very uniform layer. This yields much better pulse height resolution and lower magnetic sensitivity compared to the results from the less consistent coatings placed or activated on the dynodes after the dynodes are already installed in their locations within the tubes. Furthermore, it is very difficult and complex to coat all the dynodes of a multiple dynode tube when the dynodes are already assembled.

[0014] The invention thereby provides a secondary electron emitter surface for use in photomultiplier tubes with a gain equivalent to or greater than the prior art devices and with superior stability, but the surface is easier and less hazardous to manufacture.

[0015] The high secondary emission p-doped diamond layer dynode of the present invention can be used in various applications. Currently, in medical imaging applications, tubes are designed with large, high collection and high gain dynodes at the front end of the tubes. This lends itself to improved pulse height resolution, an important parameter for scintillation detection. P-doped diamond coated dynodes are uniform over large areas with secondary emission, and that satisfies such design criteria.

[0016] The applications for p-doped diamond coated dynodes can also be extended to latter stages of the electron multiplier. The higher gain of the dynode results in a lower number of dynodes required to achieve the desired tube gain. Electron multipliers with fewer stages require less physical space, leading to more compact and less massive imaging systems, a benefit in both medical imaging technology and photon counting applications.

[0017] The invention also provides a complete photomultiplier tube as well as a method for its manufacture as defined in the annexed claims.

BRIEF DESCRIPTION OF THE DRAWING

[0018] The FIGURE is a simplified drawing of the preferred embodiment of the secondary emitting surface of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0019] The FIGURE is a drawing of the very simple preferred embodiment of the invention in which secondary emitter 10 is formed only from p-doped diamond film 12 coated by chemical vapor deposition upon base substrate 14. Alkali metal layer 16 is then conventionally produced upon p-doped diamond film 12 during the generation of the photocathode within the tube. The alkali metal layer may be caesium, potassium, sodium, or rubidium for example. This layer may be produced after assembly of the photomultiplier tube or other devices in which the invention is used. In this case, the device is assembled with untreated diamond dynode surfaces. The device, enclosed in a glass or metal envelope is evacuated, and any of the above mentioned alkali is introduced in its metallic form at a temperature, 150°C to 250°C, where the metals exist as a vapour. Upon cooling to lower temperatures, the alkali metals deposit on the dynode surfaces yielding an activated diamond surface with high secondary emission. It should be recognised that even at higher temperatures, alkali metal will still be present on the dynode surface, maintaining its activation.

[0020] Base substrate 14 is selected from materials that promote the growth of tetrahedrally coordinated or sp3 carbon, such as refractory metals (e.g. molybdenum, tungsten, tantalum) or other carbide formers. These materials react with carbon to form carbides. These carbides have a molecular structure or chemical bonding geometry similar to that of diamond, and so the formation of such a carbide at the substrate surface promotes the growth of diamond. In addition, the thermal expansion of, for example, molybdenum is close to that of diamond, minimising interfacial stresses that might cause the diamond to separate from the substrate.

[0021] Conventional substrate 14 is typically .005 inch thick and p-doped diamond film 12 is 1-10 microns thick. P-doped diamond or diamond-like-carbon film 12 is typically applied to base substrate 14 by chemical vapor deposition or plasma deposition processes. The microstructure of the film is polycrystalline, exposing facets of a preferred crystallographic plane. The p-dopant is typically boron, and the dopant level is such that the modified resistivity of the diamond film is in the range between 600 and 1600 ohm/square.

[0022] Typically, the diamond is grown from the gas phase using a hydrocarbon such as butane, and the gas BH_3 is simultaneously admitted to the growth chamber in the appropriate amount so as to generate the desired doping level.

[0023] Secondary emitter 10 of the FIGURE can be completely prepared and processed outside the tube in which it will be used after substrate 14 is first shaped into the appropriate dynode surface, and then, after the dynode is installed within a tube, tube processing can proceed as usual.

[0024] When tested as a photomultiplier dynode, secondary emitter 10 of the preferred embodiment of the invention demonstrated that its gain is almost linear with incident beam energy, with gains of 29 at 600 volts and 48 at 1000 volts. Such a high first dynode gain results in improved pulse height resolution in tubes used for medical imaging applications.

[0025] Such measurements indicate that the present invention equals or exceeds the capabilities of the prior art photomultiplier dynodes, while also furnishing great reliability and simplicity of manufacture.

[0026] It is to be understood that the form of this invention as shown is merely a preferred embodiment. Various changes may be made in the function and arrangement of parts; equivalent means may be substituted for those illustrate and described; and certain features may be used independently from others without departing from the spirit and scope of the invention as defined in the following claims.

[0027] For example other p-dopants may be sued instead of boron, and, of course, other materials may be used for the substrate.

Claims

1. A photomultiplier tube dynode secondary electron emitter comprising a substrate and a diamond film on the substrate wherein the diamond film includes a p-dopant.

2. A secondary electron emitter according to claim 1 further including an alkali metal coating on the diamond film.

3. A secondary electron emitter according to claim 1 or 2 wherein the p-dopant is boron.

4. A secondary electron emitter according to any preceding claim wherein the substrate is a refractory

metal.

5. A secondary electron emitter according to claim 4 wherein the substrate is molybdenum, tungsten, or tantalum.

6. A secondary electron emitter according to any preceding claim wherein the quantity of p-dopant within the diamond film is sufficient to make the resistivity of the diamond film in the range of between 600 and 1600 ohm/square.

7. A photomultiplier tube having at least one secondary electron emitter as claimed in any preceding claim.

8. Method for manufacturing a photomultiplier tube having at least one dynode secondary emitter comprising a p-doped diamond film formed on a substrate, wherein the tube is enclosed in an envelope, the envelope is evacuated and an alkali metal is introduced at a temperature such that the metal is in vapour form.

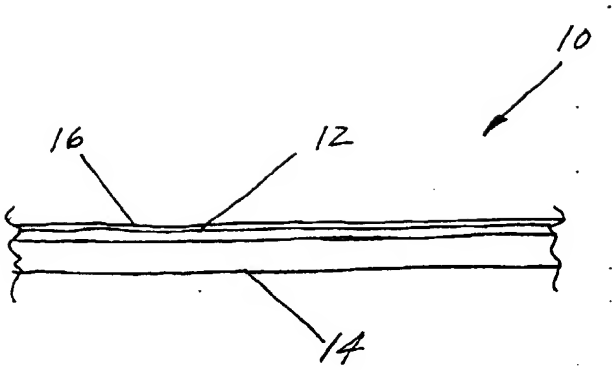

FIG 1